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Physical and mechanical properties of waterlogged wood treated with hydrolyzed feather keratin

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ABSTRACT

The physical and mechanical properties of waterlogged wood treated using avian feather were investigated. Avian feather is mainly composed of keratin protein and expectable materials for industrial utilization. The feather hydrolysate enhanced the mechanical properties of waterlogged wood and recovered the correlations between modulus of rupture (MOR) and modulus of elasticity (MOE) and anisotropy. The color of the wood treated with hydrolyzed feather solution exhibited natural wood texture. The feather hydrolysate had antimicrobial activity. However, the wood treated with hydrolyzed feather solution showed high hygroscopicity.

1. Introduction

Archaeological waterlogged woods are found from archaeological sites under river swamps or the sea. The wood has been degraded by microorganisms but the original dimensions have been preserved by water filling in the pores. Chemical analysis of waterlogged wood indicates a great loss of chemical components by degradation. Thus, drying of waterlogged wood without treatment poses a risk of collapse. Polyethylene glycol (PEG) was used for stabilizing dimensions of waterlogged wood excavated in 1850s (Christensen, 1970). Nowadays, the PEG method is performed for conservation of waterlogged wood all over the world. However the PEG method is not universally useful for all kinds of artifacts. Therefore, improved PEG treatments for different artifact are still being investigating, such as freeze-drying or two-step PEG treatment (Hoffmann, 1986).

We developed a new treatment for archaeological waterlogged wood using avian feather (Endo et al., 2008). Avian feather is one of several biomass resources that have been examined as sustainable materials in recent years. Feather is composed of mainly keratin protein and the molecular mass of feather keratin is lower than that of other keratin proteins such as wool or hair keratins. Therefore, various uses for feather keratin have been developed, such as a substrate for cell culture medium (Poopathi and Abidha, 2008), production of enzymes (Azeredo et al., 2006) and material of fiber composites (Bullions et al., 2006). We confirmed that the new conservation treatment using avian feather provided good stabilization for waterlogged wood (Endo et al., 2008). To establish this treatment as a practical method, some basic properties of the wood treated with avian feather should be discussed from the point of view of display and storage. Therefore, a series of experiments were performed to clarify the various properties of the wood treated with hydrolyzed feather solution such as physical and mechanical property, color property, antimicrobial activity and hygroscopicity.

2. Materials and methods

2.1. Waterlogged wood specimens

Waterlogged wood specimens were collected from several archaeological sites dating from the 4th to 9th century in Japan. Camphor (*Cinnamomum camphora* Presl) was prepared for mechanical and hygroscopic tests and *Aphananthe* oriental elm (*Aphananthe aspera* Planch.) for color measurement and antimicrobial activity.

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2.2. Preparation of hydrolyzed feather solution

Feather was provided by Toyo feather industry (Kanagawa, Japan). Ten grams of duck feather were dissolved in 90 mL 1 N sodium hydroxide solution at 70 °C for 3 h. Acetic acid was added to neutralize the solution (pH 7.0). More concentrated solutions were obtained by concentrating the original in 10 wt% steps. Polyethylene glycol (PEG) was purchased from Sanyo chemical industries (Kyoto, Japan). The molecular weight of PEG was about 3300.

2.3. Impregnation

Camphor wood and *Aphananthe* oriental elm wood were cut into blocks measuring 100 (T) × 100 (R) × 200 (L) mm and 30 (T) × 30 (R) × 10 (L) mm respectively. The blocks were immersed into 10 wt% hydrolyzed feather solution at 60 °C and the concentration of the solution was raised every 8 days in steps of 10 wt% finally to 30 wt%. For PEG impregnation, the blocks were immersed into 20 wt% PEG solution at 60 °C and the concentration of the PEG solution was raised every 10 days in steps of 20 wt% finally to 100 wt%. The blocks were dried until the weight reached a plateau (20 °C and 60% relative humidity).

2.4. Measurement of dimensional stability

Stainless steel pins were applied to the cross-sectional surface of camphor wood blocks along tangential and radial directions respectively. The dimensional stability was evaluated by the distance between the pins of saturated wood without any chemical treatment and of air-dried wood treated with PEG and hydrolyzed feather solution. Shrinkage (β) and shrinkage in cross-section (β_{cs}) were calculated as follows;

$$\beta(\%) = \frac{l_u - l_t}{l_u} \times 100$$

$$\beta_{cs}(\%) = \left[1 - \left(1 - \frac{\beta_t}{100}\right)\left(1 - \frac{\beta_r}{100}\right)\right] \times 100$$

where, l_u and l_t are the distances between the pins of saturated wood without any chemical treatment and the pins of air-dried wood treated with PEG and hydrolyzed feather solution, respectively. Where, β_t and β_r are shrinkages in the tangential and radial directions, respectively. Anti-shrink efficiency (ASE), as an indicator of dimensional stability of wood, was calculated as follows;

$$\text{ASE} = \frac{S_c - S_t}{S_c} \times 100$$

where, S_c is shrinkage in cross-section of air-dried wood without treatment and S_t is shrinkage in cross-section of treated wood.

2.5. Evaluation of mechanical properties

Specimens for measurements of mechanical properties were cut from the blocks that had finished PEG or feather hydrolysate treatment. The specimens measured 3 mm wide by 14 mm long by 86 mm thick. All specimens were conditioned at 20 °C and 60% relative humidity (RH) for a week. A three-point bending test was performed using a test instrument (A&D, Tensilon UTM-4L) with a span length of 50 mm for radial–tangential and 60 mm for longitudinal direction at a crosshead speed of 5 mm/min (Green et al., 1999). Ten specimens were prepared for respective tests and the specimens with defects were removed. Modulus of rupture (MOR), modulus of elasticity (MOE) and proportional limit (PL) were calculated as follows:

$$\text{MOR}(\%) = \frac{3Pl}{2bh^2}$$

$$\text{MOE}(\%) = \frac{\Delta Pl^3}{4\Delta y bh^3}$$

$$\text{PL}(\%) = \frac{3Pl}{2bh^2}$$

where, P is the maximum load in the case of MOR and the load at a point below the proportional limit in the case of PL. Where, ΔP is the difference between maximum load and minimum load in the proportional limit. Where, l is the span length (mm), b is the width of specimen (mm) and h is the thickness of the specimen (mm). Where, Δy is the deflection corresponding to the load.

2.6. Scanning electron microscopy

Cross-sections of the specimens were coated with gold under 10^3 Pa and scanned using scanning electron microscopy (Hitachi-Science, S-3000N) operated at 15 kV and 55 μA under approximately 10^{-4} Pa.

2.7. Color property

The color property of the treated and present wood specimens was measured using a spectrophotometer (Konica Minolta, CM-1000). The data obtained were indicated at $L^*a^*b^*$ system.

2.8. Antimicrobial activity

Antimicrobial activity of feather hydrolysate was determined as follows. An aliquot of *Escherichia coli* was grown in Luria-Bertani (LB) medium at 45 °C. Air-dried wood specimens without treatment and feather hydrolysate treated wood specimens were put on the LB agar medium irradiated by ultraviolet. After the incubation at 37 °C in an incubator for 24 h, the zone of inhibition was observed.

2.9. Hygroscopic property

Specimens of 14 (T) × 43 (R) × 3 (L) mm for hygroscopic test were cut from the blocks that had been treated with PEG or hydrolyzed feather solution. The specimens were exposed in desiccators at constant temperature of 25 °C, with increasing relative humidity of 56%, 75% and finally 95% every week. Hygroscopicity was evaluated from the weight of specimens measured with each relative humidity. Where, M is moisture content; G_0 and G_t are the weight of the oven-dried specimen and the weight of the saturated specimen, respectively.

$$M(\%) = 100 \times \frac{G_t - G_0}{G_0}$$

The swelling (S) of treated wood was calculated from the formula below. V_0 and V_t are the oven-dried volume of specimen and saturated volume of specimen, respectively. Results are the mean values from three replicate specimens.

$$S(\%) = 100 \times \frac{V_t - V_0}{V_0}$$